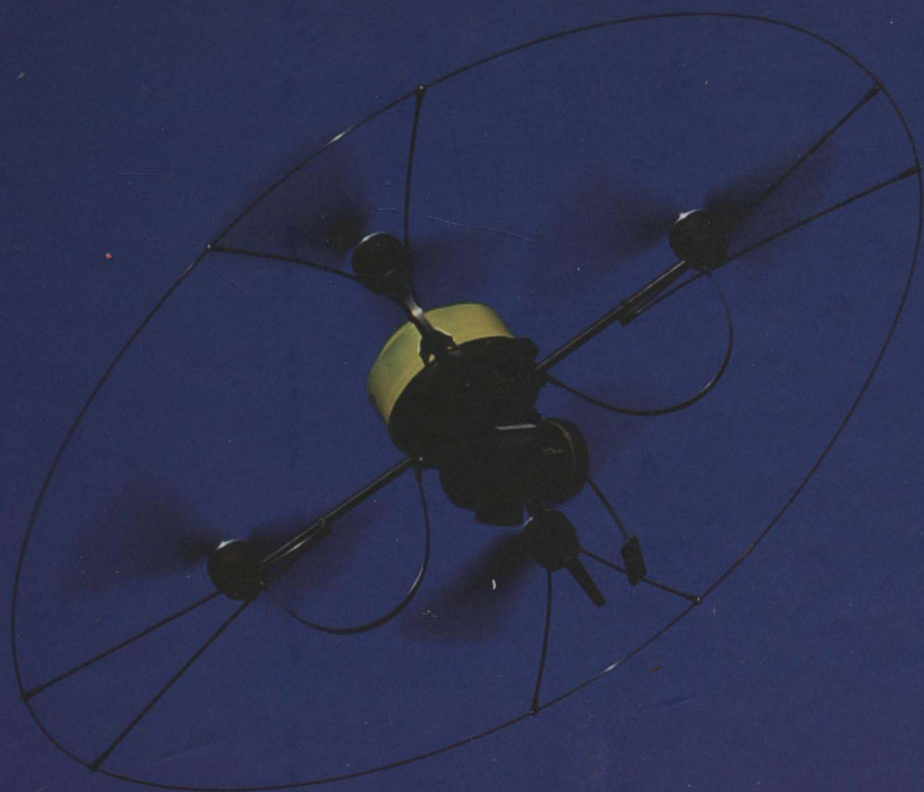
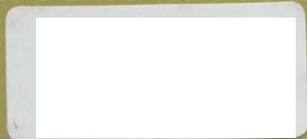


DISASTER ROBOTICS

ROBIN R. MURPHY



Disaster Robotics

Robin R. Murphy

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Disaster Robotics

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To Kevin, Kate, and Allan



Preface

The purpose of this book is to provide a comprehensive resource for researchers, practitioners, and the public on the use of robots for any type of disaster. The recent series of earthquakes, tsunamis, oil spills, and mine disasters has heightened the awareness of the value of robots for response and recovery as well as for prevention and preparedness. The book is intended to serve as an *introduction* for researchers and technologists who need to understand the domain and the state of the art to apply their research and development expertise to this emerging field; as a *reference manual* for agencies and emergency managers on the state of the practice; and as a *textbook* for students in field robotics and human–robot interaction. The book also acts as a *history* of disaster robotics for the public and science writers seeking to place current technologies in context with past innovations or deployments and to project future uses and challenges.

Motivation

The motivation for writing this book stems from my engagement with disaster robotics, now approaching 20 years. My primary goal is to pull together the objective data and published findings about disaster robotics from all sources in more detail than captured in the chapter on search and rescue robotics that I co-wrote with many colleagues for the *Handbook of Robotics*. My secondary goal is to share my “up close and personal” experiences from the field. As a field researcher, I have adopted many methods from anthropology and cognitive science, especially the technique of reporting case studies. Though my experiences do not support statistical inference, the case studies offer a narrative on the complex sociotechnical ecology within which robots must function. I also hope that the case studies impart at least some of the sense of excitement and discovery that has made my career so rewarding.

My involvement in disaster robotics started in 1995, when my research shifted from artificial intelligence for mobile robots in general to artificial intelligence specifically for disaster robots. The shift came in the aftermath of the twin disasters of that year: the bombing of the Alfred P. Murrah Federal Building in Oklahoma City in the United States and the Kobe earthquake in Japan. One of my graduate students at the Colorado School of Mines, John Blitch, then a U.S. Army major with search and rescue training, participated in the response at the Oklahoma City bombing. His experiences motivated his master's thesis that combined artificial intelligence and operations research to analyze the utility of rescue robots, and they were also responsible for my conversion to disaster robots.

My disaster robotics research shifted from the laboratory to the field in 1999 after my move to the University of South Florida. At the University of South Florida, my group began working with the Hillsborough County Fire Rescue Department and Florida Task Force 3. Under the tutelage of Chief Ron Rogers, we had to discard most of our laboratory-based research in artificial intelligence and marsupial platform designs where a mother robot would carry and deposit a daughter robot. The research was not addressing the needs or the realities of fire rescue operations. I drew on my fond memories of an anthropology course that I took as an undergraduate and started conducting ethnographies during exercises, creating the foundation for my work in human-robot interaction. We began routinely participating in exercises and even taking response classes to learn more about the realities of disaster response. The fieldwork changed not only our research but also the type of equipment we purchased with grants, how we packed and stored the gear for ease of transportation to field exercises, the tools and spare parts we brought along, and the data we learned to collect.

The shift from field research to actual deployments started in 2001. On September 11, 2001, my group joined the Center for Robot-Assisted Search and Rescue (CRASAR) for the response to the collapse of the World Trade Center, the first reported use of rescue robots. CRASAR had been formed 2 weeks earlier by John Blitch. He was in the process of stepping down as the manager of the Defense Advanced Research Projects Agency (DARPA) Tactical Mobile Robots program, which created the iRobot Packbot, QinetiQ Talon robots, invested in the Inuktun series of microrobots, and inspired the Dragonrunner and throwable robots. He wanted to use CRASAR to push for the use of small military robots in emergency response, which was eerily prescient. At the World Trade Center, the 2 years of fieldwork allowed my team to contribute to the response: Our small robots were the most heavily

used, we set up the data collection and archiving processes, we provided tools, and we could speak the lingo.

In 2002, I became the director of CRASAR when John resigned to return to military service in Afghanistan. Under my direction, CRASAR has continued to lead the way in deploying robots, including the first deployment of unmanned surface vehicles, which was at Hurricane Wilma in 2004, and the first deployment of small unmanned vehicles at Hurricane Katrina in 2005. The CRASAR cache of tactical ground, aerial, and marine robots remains on call 24/7, and upon my move to Texas A&M University, we established the *Roboticians Without Borders* program to match robots from industry and agencies with disasters. CRASAR also trains emergency managers and responders all over the world about robots and how they can, and have, been used. Other agencies have adopted robotics, and the deployments have begun to accelerate.

Within the academic community, I have been active in establishing disaster robotics and human–robot interaction as a recognized discipline within robotics and automation, cofounding an annual scientific conference, the IEEE International Symposium on Safety, Security, and Rescue Robotics, and hosting numerous workshops and tutorials. I have continued to publish and conduct basic research in my field. These activities have exposed me to other perspectives on rescue robotics and allowed me to witness the growing interest in, and frequent questions about, disaster robotics.

Now, with more than a decade of deployments and research since the collapse of the Twin Towers of the World Trade Center, disaster robotics has matured, and the range of deployments is sufficiently broad to merit a comprehensive examination of the field. As of April 2013, I personally have the most experience with those deployments of robots (15 of 34) and in formally analyzing the performance of robots at those 15 deployments and at 8 other disasters. This gives me a unique position from which to synthesize the state of research and the state of the practice in disaster robotics.

Content and Convention

This book uses several features designed to promote learning and to stimulate further reading and discussion. Each chapter begins with a statement of objectives and ends with a summary to help the reader to find information of value. Chapters 2–5 include a section on common misperceptions about the topic for that chapter, the gaps between theory and practice, and what research directions are suggested by those gaps. Case studies are

interspersed, and they illustrate particular technologies and the role of the robots in the larger emergency enterprise.

The book is divided into six chapters, as follows:

- Chapter 1 provides a broad overview of rescue robotics in the context of the larger emergency informatics enterprise, the specific missions, and the major applications of robotics by the type of disaster.
- Chapter 2 presents a summary of the 34 deployments of robots to disasters worldwide in chronological order and offers a formal analysis of how well they have performed their missions and where and why they have failed and the general trends.
- Chapters 3, 4, and 5 describe the typical disaster robot modalities: ground, aerial, and marine, respectively. Each of these chapters follows the same organization of content to enable the reader to compare and contrast the modalities. The chapters repeat and expand on the material from chapters 1 and 2, so that a reader interested only in one modality, say unmanned aerial vehicles, can go directly to the relevant chapter to find
 - the types of robots within that modality;
 - the environments they are expected to operate in, the missions and tasks, and where they have been used;
 - the selection heuristics for determining if that modality is appropriate for a disaster; and
 - the surprises, gaps, and open research questions.
- Chapter 6 describes the types of fieldwork and provides practical advice in planning and conducting fieldwork, what data to collect and how, and working with emergency professionals.

In addition, a list of acronyms and abbreviations and a glossary are found at the back of the book.

The book is written largely in third person but uses a first person point of view in two different situations. First person is used for the case studies in keeping with ethnographic reporting norms and because based on more than 20 keynote addresses and tutorials, I have found that first person storytelling encourages the reader to relate to the realities of disasters and think more closely about how to apply the principles that are distilled in this book. First person is also used to distinguish when material is from the corpus of studies that I as a scientist have contributed to or when the analysis is based on my personal experience. While this book is intended to be a distillation of the entire field and should neutrally reflect the state of the art, my biases most certainly appear, and first person alerts the reader to that possibility.

The book uses boldface and italic to help highlight material. Boldface is used for definitions and important concepts that an instructor may wish to emphasize or test over, and italic is used for emphasis.

Acknowledgments

I have many people and organizations to thank for their help: funding agencies, the two universities I have worked at during the evolution of disaster robotics, the professional responders, team members, my students, the MIT Press, and above all, my family.

This book could not be possible without the research funded by the National Science Foundation (NSF), the Mine Safety and Health Administration (MSHA), the Defense Advanced Research Projects Agency, the Office of Naval Research (ONR), the Army Research Laboratory (ARL), Microsoft Research, the Global Center for Disaster Management and Humanitarian Assistance at the University of South Florida, and the Florida High Tech Corridor. Rita Rodriguez at NSF and Jeff Kravitz at MSHA have been especially supportive. The gifts from SAIC through Dr. Clint Kelly combined with my endowment from Raytheon and donations from SeaBotix to our Roboticists Without Borders program have helped cover the costs of deployments, exercises, and training for responders.

The University of South Florida and Texas A&M University have been wonderfully supportive. My colleagues at the University of South Florida covered my classes for fall 2001 to allow me to analyze the lessons learned from the World Trade Center and travel to promote rescue robotics. Everyone there encouraged me to “go for it,” giving me the freedom to help create a new scientific discipline. The faculty and students at Texas A&M remain an inspiration with their ideas, encouragement, and accommodation of my sudden disappearances. I am grateful to work with the Texas A&M Engineering Extension Service, learning from world leaders in all facets of public safety and using its excellent facilities such as Disaster City®.

Countless emergency response professionals have shared their insights and time, but I particularly want to thank the following individuals and groups: Ron Rogers, Hillsborough County Fire Rescue, and Florida Task Force 3 gave generously of their time and expertise, and Mike Gonzalez opened the doors to the Tampa Fire Training Academy and their experts. Bill Bracken actively involved us in structural forensics. Justin Reuter and Indiana Task Force 1 adopted CRASAR after September 11, 2001, and their technical search team manager, Sam Stover, remains an integral part of CRASAR and has organized several of our deployments. No greater love

has an Indianapolis urban search and rescue team than to give up going to the Brickyard 400 in order to host a comprehensive search and rescue exercise for 20 scientists for our first Summer Institute. Jim Bastan with New Jersey Task Force 1 became the first adopter of rescue robots in the United States and remains a source of great ideas. New Jersey's disaster training facilities remain my second favorite place on Earth, just second to Disaster City®. John Holgerson and Joe Sorrentino of Rescue Training Associates incorporated us into training events at major demolitions all over the country, often with a large cadre from Florida Task Forces 1 and 2 out of Miami; it is now difficult to conduct a response exercise without a shot of Cuban coffee. Geoff Williams from the United Kingdom, who remains an inspiration, and Jacques du Plessis at Rescue South Africa engaged us on an international scale. California Task Force 2 and California Task Force 1 hosted us for a rescue robotics awareness training exercise for the Los Angeles basin, followed by Los Angeles County Fire Rescue training us on their confined-space rescue techniques. The U.S. Marine Corps Chemical Biological Incident Response Force (CBIRF) continues to educate me on hazmat responses, and the 10 days I spent for their CBIRF boot camp has had a major impact on how I conceptualize the diversity of roles of robots for disaster response. Virginia Task Force 2 and Missouri Task Force 1 also have been great. The response experts at the Texas A&M Engineering Extension Service and Texas Task Force 1 have also been helpful, with Billy Parker offering insights into where and how robots could be deployed long before I moved to Texas A&M. Kem Bennett, who was the dean of engineering at Texas A&M, the founder of Texas Task Force 1, and the creator of Disaster City®, remains a role model. Clint Arnett is our go-to guy and has organized countless exercises, Summer Institutes, and experiments at Disaster City® and has deployed to Cologne, Germany, with me—how it all works is a mystery but a fun one. Bob McKee co-hosted several Summer Institutes at Disaster City® with me and served as a co-principal investigator on an NSF grant, and David Martin, Susan Brown, and Matt Minson have been highly supportive.

This book also benefits from the experiences of everyone who has participated in deployments, but Sam Stover and Eric Steimle deserve special thanks. They help me organize resources and responses, and they volunteer their time and talents in keeping up with the best systems that are emerging from industry and in promoting rescue robotics. I would like to thank all the people I've deployed with: Fred Alibozek, Mike Bruch, John Blich, Jennifer Casper, Mike Ciholas, Bart Everett, Tom Frost, Jay Haglund, Robin Laird, Arnie Mangolds, Mark Micire, Brian Minten, Grinnell Moore,

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I want to thank my students and postdoctoral students for continuing to teach me as much as I teach them and for the great times we have exploring new ideas and insights. John Blicht, Jenny Burke, Jennifer Casper, Jeff Craighead, Mark Micire, Brian Minten, and Kevin Pratt have been extraordinary in the gifts of their time and hearts to the humanitarian use of robots and have deployed to disasters. Cindy Bethel, Brian Day, Brittany Duncan, Jennifer Carlson, Thomas Fincannon, Rachel Flores-Meath, Aaron Gage, Marco Garzo, Zack Henkel, Jeff Hyams, Elliot Kim, Mike Lindemuth, Matt Long, Josh Peschel, Tanner Perkins, Brandon Shrewsbury, Vasant Srinivasan, Jesus Suarez, and Rosemarie Yagoda have spent countless hours at exercises and in the field and helping to support teams at deployments. Marco Garza, Edgardo Calzado, and Tanner Perkins have served as student laboratory managers with the hidden but essential task of keeping CRASAR ready to go at a 4-hour notice.

Marie Lee, Ada Brunstein, and Bob Prior at the MIT Press have guided the publishing of this book and the anonymous reviewers provided excellent feedback. Christopher Curioli, who copy edited this volume for the MIT Press, was outstanding; he helped the book maintain a consistent pedagogical focus and counteracted my tendency to overuse italics for emphasis which had created a reading experience suitable for delivery by William

Shatner, where everything (pause) is (pause) important. I especially want to thank Brittany Duncan, Rachel Flores-Meath, Zachary Henkel, Elliot Kim, Tanner Perkins, Vasant Srinivasan, Brandon Shrewsbury, and Jesus Suarez for their critiques of early drafts and numerous contributions to the overall organization and figures.

I could not have written this book or conducted the work upon which it is based without the support of my family. After the deployment to the September 11 disaster, it was clear that there needed to be an active advocate of rescue robotics for adoption and for researchers and industry to recognize the special demands of emergency response. The other CRASAR participants were being re-absorbed into their day jobs, so either I was going to have to step up and be the advocate or no one would. However, that would entail a huge cost in time and travel; indeed I gave more than 50 talks on rescue robotics to agencies and at conferences in the first year alone. My husband, Kevin, our two children, Kate and Allan, and I made the decision together, and they have been totally supportive during my long hours away from them. I could not do any of this without Kevin.

Any errors herein are solely mine, and I fervently hope they are minor and do not distract or mislead anyone in the quest to make and use robots to assist in disaster prevention, preparedness, response, and recovery.

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